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THIS ISSUE

Hydraulic
Power Steering
for Passenger Cars

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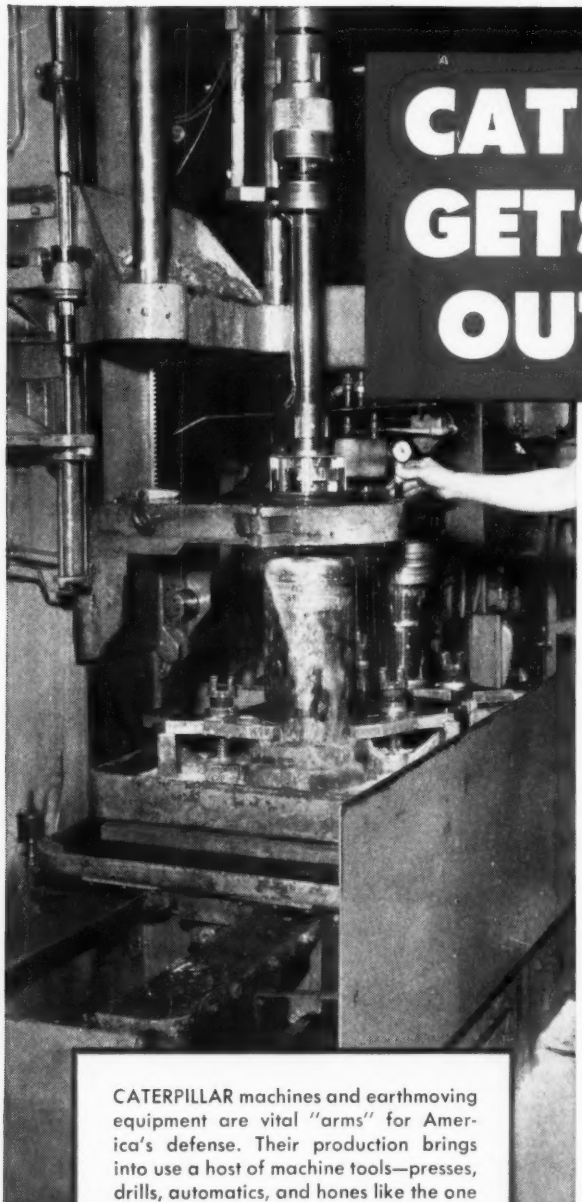

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LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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Hydraulic Power Steering for Passenger Cars

POWER STEERING is certainly not a new development since even the horse and buggy was steered by power (the horse). But when the early horseless carriage engineers unharnessed the flesh-and-blood horse and bolted in a herd of mechanical horses, they ignored this basic fact, thereby forcing several generations of drivers to do their own work. The faithful horse was no longer available to steer the carriage under the driver's control: instead the driver had to supply both steering power and control.

Why Power?

As long as our predecessors were content with light bicycle-tired horseless surreys, steering effort was insignificant, particularly by comparison to the considerable power required to crank their engines or to push them home. A simple tiller bar having the "fast" overall steering ratio[1] of about one to one sufficed to guide them. But as vehicle weights increased, it became increasingly difficult to guide their front wheels. In tardy recognition of the limited strength of the driver, some early designer evolved the first steering *gear* by substituting a steering wheel for the old tiller bar and placing a torque-multiplying reduction gear between the steering and road wheels. The adverse effect on steering of further increases in weight, particularly in trucks and buses, was partly offset by increased steering ratios with the result that some are close to 40 to 1. While such a high ratio may sufficiently multiply the driver's pull at the rim of his steering gear to permit steering of sorts, the sensitivity or "feel" of the road is greatly reduced; furthermore in an emergency too much precious time is lost in "winding up" a high ratio gear. Flying elbows during such an emergency are in themselves hazardous! Even engineers frequently do not realize that the universal use of inclined king pins to obtain automatic straightening of front wheels has had a detrimental byproduct: during any movement of a front wheel, the driver through his steering gear must actually lift all of the weight on both front wheels! During the development period substantial gains were also made in steering gear *efficiency* or better utilization of the driver's force by substituting rolling for sliding surfaces throughout the steering system. In spite of all these improvements, the continually increasing front-wheel weight of some commercial and military vehicles forced their manufacturers to be the first to adopt power steering as standard production equipment. In short we have again substituted limitless mechanical horsepower for our restricted human strength: with power steering we are again the ruler rather than the slave.

Although power steering gears for trucks and buses are generally similar to those on passenger cars, they are outside of the scope of this article.

Although Francis W. Davis demonstrated a highly successful power steering gear before major passenger car manufacturers as early as October of 1926, the manufacturers of even the heaviest

[1] Number of degrees turn of the steering wheel required to turn a front road wheel one degree around its king pin.

passenger cars were able to husband the diminishing margin of driver ability over car requirement until late 1950 when Chrysler announced the availability of power steering as standard equipment on the 1951 Crown Imperial and optional equipment on other Chrysler eights. Other passenger car manufacturers quickly unveiled their parallel developments, and the long-delayed boom in power steering not only began with a rush, but is being rapidly extended to our so-called light cars by virtue more of its delightful convenience and luxury than stark necessity. The ladies (who are doing most of our driving and buying) are particularly quick to appreciate and demand the emancipation that only power steering can give from the brute strength rigors of parking a car. Suffice to say that something over 200,000 power steering units were produced during 1952 (as against 10,000 in 1950), and the twenty-fold increase is almost entirely due to passenger cars.

Why "Hydraulic" Power?

We are agreed that power should or must be used to assist the driver in driving his vehicle: Only the source and method of use remains to be investigated.

The only sources of power already available in a passenger car are the storage battery and the engine. While electrical power has been used experimentally, the requisite one horsepower motor is heavy, expensive and bulky, and the poor battery and generator are already overloaded by other requirements. However, the engine's power is usable either directly as mechanical power, or indirectly by driving an air compressor, or by utilizing intake manifold vacuum, or by driving a hydraulic pump. Mechanical power utilizing two engine-driven oppositely rotating clutch systems around the steering column was patented in 1927 though never pursued: very recently a somewhat different approach has been developed and will be announced shortly after the appearance of this article. Compressed air is superficially attractive as a source of power, particularly if the vehicle already has an installed air compressor, and some air steering systems have been used commercially to a very limited extent. Since air compressors are bulky and expensive, the air itself is a compressible medium not easily adapted to the precise and rigid control required in a steering system, and since a maximum air pressure of say 100 psi would necessitate a large diameter steering gear piston to develop the requisite large steering assistance forces, air must be rejected for this purpose. Intake manifold vacuum must also be rejected much more emphatically for the same reasons and also because of the extremely large size of the vacuum equipment required which must operate on a maximum of only 10 psi negative pressure.

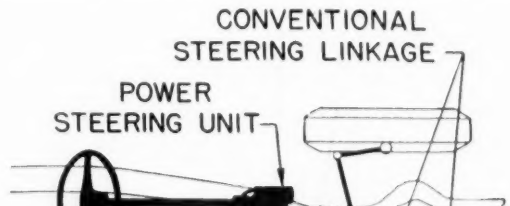
But hydraulic power offers many advantages, for example the following: its inherent self-lubricating characteristic; where desirable, the ease and practicability of developing pressures well in excess of 1000 psi, with pump speeds up to 8000 RPM; the ability to develop extremely high forces in small spaces; the ready adaptability of hydraulic mechanisms to available irregular-shaped spaces; the extreme precision of movement control afforded by the relative incompressibility of a liquid; the ease and speed with which large forces can be applied, removed, balanced, modulated and absorbed; the practicality of constructing a closed system by avoiding intake, discharge or vent holes that are likely to admit contaminants. Only a few such advantages are sufficient to explain the fact that all passenger car power steering systems presently marketed are of the hydraulic type.

THE CHRYSLER-DESOTO (GEMMER) POWER STEERING SYSTEM

This gear, the first to be applied in production quantity to passenger cars (Chrysler, DeSoto) is of the "integral" type, that is, the hydraulic power pistons and the hydraulic sensing and control mechanisms are all in one highly-compact assembly directly associated with the conventional steering gear. A second similarly-compact assembly containing the hydraulic pump and oil reservoir is simply connected to the first by two flexible hoses.

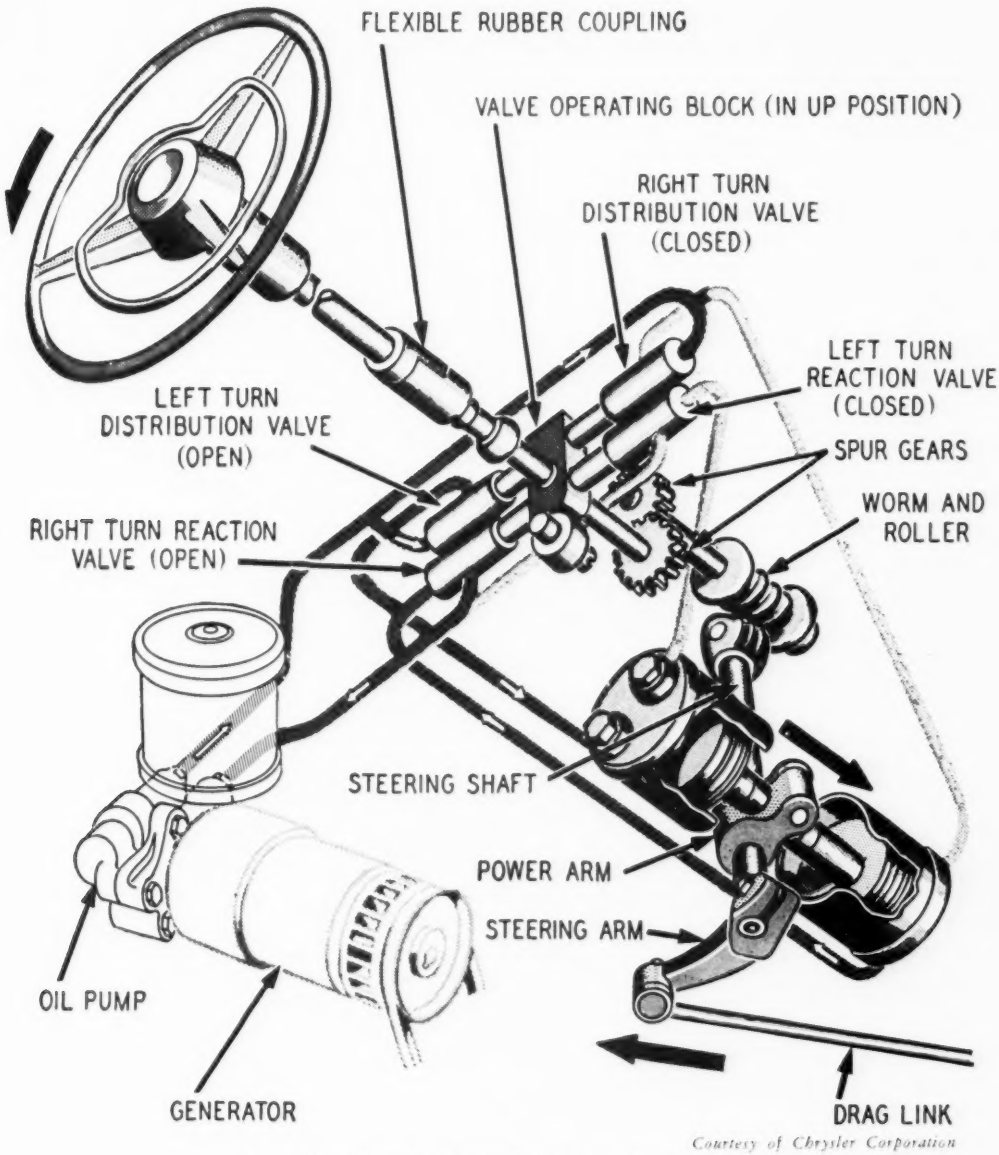
Figure 1 schematically illustrates the installation of such an integral power steering unit, its two hydraulic connections to the engine-driven hydraulic pump, and its relationship to the otherwise conventional steering linkage and front wheels.

Figure 2 is a greatly enlarged schematic representation of the power unit itself with its pump. Since the pump is the source of power assistance or motivating force, a logical beginning is best made



Courtesy of Chrysler Corporation

Figure 1—Installation of Integral-Type Power Steering System.



Courtesy of Chrysler Corporation

Figure 2 — Schema of Chrysler-DeSoto Power Steering System.

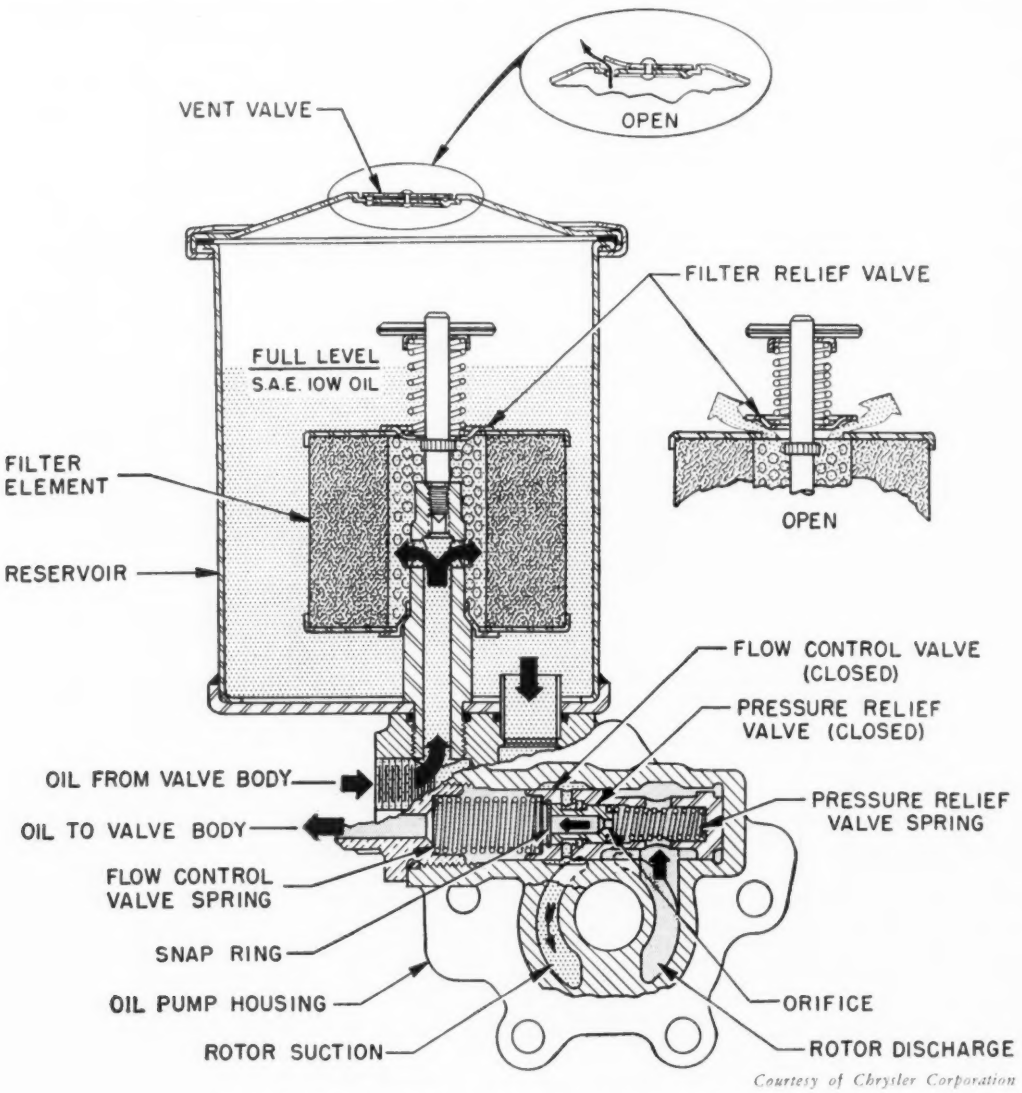
with this unit, as illustrated by Figure 3. The latest pump is of the six-lobed single rotor type driven through a flexible coupling from the rear end of the generator shaft. The pump intake port is connected through drilled passages (not shown) communicating with the oil reservoir *outside* of its replaceable paper filter element. Oil from the pump rotor flows through the flow control valve and a hose to the valve body of the power steering unit. A closer examination of the necessity for the flow control valve is desirable. The major volume requirement of the hydraulic system occurs during parking operation when the engine is idling and the pump is therefore delivering its minimum discharge, consequently a large-capacity pump (1½ gpm and 600 psi at engine idle) must be installed. Without modification, such a pump would deliver enormous and wholly unnecessary quantities of oil at normal driving speeds with consequent power losses, therefore the ingenious flow control valve is provided. Referring again to Figure 3, it can be seen that this valve consists of a spring-loaded hollow piston surrounding a second spring-loaded piston (the pressure relief valve) having a calibrated orifice in its head. Whenever the pump attempts to deliver more than its required 1.5 gpm

the increased differential pressure across the orifice forces the flow-control piston to the left and uncovers enough of an annular relief groove in the valve body communicating with the pump intake to relieve the excess differential pressure, thus controlling pump delivery *volume*. The small internal pressure-relief valve limits maximum oil pressure under any condition to 750 psi by moving to the right and uncovering relief holes in the flow-control piston which also communicates with the pump intake.

Oil returning from the power steering unit through the second hose is discharged to the interior of the filter element. Since cold and viscous oil under pressure could rupture the filter, a relief valve which opens at about 7 psi and by-passes the filter is provided. Since the entire system is closed to promote general cleanliness and particularly to avoid oil contamination, a small low-pressure vent valve is also provided which relieves excess air pressure as the system is warmed up.

Reverting to the upper portion of Figure 2, it will be seen that the power steering unit itself consists essentially of the basic all-mechanical worm-and-roller type gear, a pair of opposed power pistons operating against their own lever on the steering shaft, a pair of valves on each side of a valve operating block, and (what appears to be) a normal steering wheel and column.

Closer examination will show however that the



Courtesy of Chrysler Corporation

Figure 3 — Chrysler-DeSoto Power Steering Oil Pump and Reservoir.

steering column is divided into two sections and connected by a rubber coupling so designed that it transmits driver torque readily without rotary backlash, but allows the lower section of the shaft to pivot slightly out of line. The lower shaft is provided with a spherical bearing at its upper end and one of a pair of spur gears at the lower end, the intermediate section passing through and rotating in the valve operating block. Bearing against the valve operating block from both sides are the four sleeve valves which control the amount and pressure of oil admitted to or discharged from the two power cylinders.

Although normally identical and interchangeable (as assemblies) the four operating valves detailed in Figure 4 are divided into two specialized groups according to their purposes, — two "distribution" and two "reaction" valves. When open, a *distribution* valve admits high pressure oil to its power cylinder while an open *reaction* valve vents or permits oil to escape. Each of the two power cylinders is therefore connected through inflexible high pressure steel tubing to both its individual distribution and reaction valves. The two valves controlling a given power cylinder are arranged on opposite sides of the valve operating block so that its movement will close one while opening the other still wider. When the valve operating block is in its central or neutral position, *all* valves are partially open and oil at comparatively low pressure can therefore circulate freely through them and their cylinders. Unlike the schematic Figure 2, Figure 4 shows that the two valves of each type are actually located directly across the operating block from each other with the reaction valves closer to the steering shaft. The relative positions of the three annular grooves in any valve and its corresponding sleeve are machined so accurately that less than 0.003 inches movement (a hair's breadth!) will start the application of hydraulic power. A coil spring and hydraulic pressure combine to keep each valve in intimate contact with, and responsive to, the slightest movement of the valve operating block. A small internal thimble with check valve and bleed orifice in each valve serves as a dash pot to minimize valve chatter and "hunting." The numerous round black dots in Figure 4 are cross-sections of annular synthetic-rubber "O" rings, the most modern method of obtaining hydraulically tight joints.

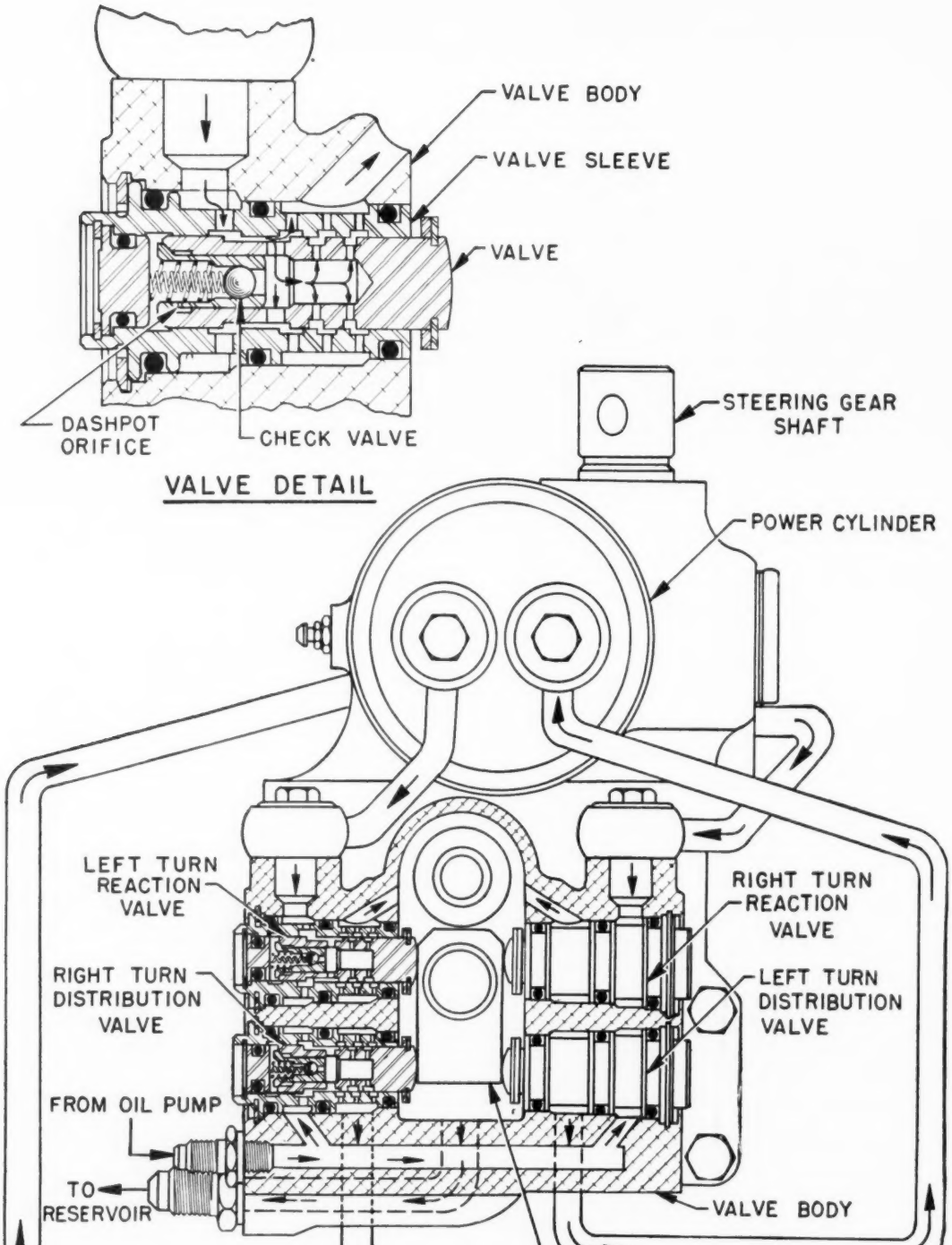
Reverting momentarily to Figure 2, the uppermost power cylinder is used exclusively for left turns, the lower for right turns. The aluminum pistons are rigidly fastened to a "piston connector" and therefore move as a single unit within their separate drawn-steel cylinders. Minimum clearance between the pistons and the roller on the piston arm assembly is obtained by adjustable hardened steel shoes. Each piston is sealed in its cylinder by means of two unique piston ring assemblies, each comprising a synthetic rubber "T" ring protected on each side by two flat phenolic plastic rings.

The entire oil system of the Chrysler-DeSoto power steering system requires only three pints of a high quality SAE 10W motor oil to fill to a level $1\frac{1}{4}$ inches below the top of the cover gasket. When atmospheric temperatures are consistently below minus 10°F., either SAE 5W motor oil or a mixture of $2\frac{1}{2}$ pints of SAE 10W oil and $\frac{1}{2}$ pint of kerosine should be used, and the engine run about three minutes each time before turning the wheel or moving the car. The 10W motor oil level should be checked every 1000 miles: the 5W or diluted 10W should be carefully replaced with 10W motor oil as soon as atmospheric temperatures are again consistently above minus 10°F. The steering gear "chuck" (the mechanical worm and roller) is lubricated with about six ounces of non-fluid steering gear grease of NLGI No. 0 or No. 1 consistency.

The unusual and ingenious construction of the pivotable steering column is the heart of the Chrysler-DeSoto Power Steering control system. To illustrate its operation refer again to Figure 2 and suppose that a driver starts to turn the steering wheel counter-clockwise in the usual manner to make a left turn. Tire friction and other opposing forces transmitted through the steering system cause that spur gear on the steering worm shaft to resist movement; as a consequence of the driver's action the second spur gear on the steering shaft will attempt to "climb" or rotate around its stubborn mate, thereby shifting the valve operating block upwards from its normal central neutral position which closes the upper pair of valves while opening the lower pair more widely. By reference to the foregoing it will be determined that this shift of valves admits high pressure oil to the upper left-turn cylinder while simultaneously exhausting oil from the other, thus applying torque to the steering shaft, and instantly providing powerful assistance to the driver.

The unique positioning of the valve mechanism results in a modulated control giving a "proportional feel" in which the driver's effort is always a fixed percentage of the total work being done by the hydraulic system. The "full-time" power steering is therefore doing its major percentage of work regardless of the maneuver (parking, cornering or driving down a straight crowned road) and under the direction and "feel" of the driver.

As soon as the driver stops applying his puny torque and merely "holds" the steering wheel, the valve operating block maintains the degree of hydraulic pressure being communicated to the power cylinder, and the front wheels respond by "holding" the degree of turn selected.



Courtesy of Chrysler Corporation

Figure 4 — Cross-Section, Chrysler-DeSoto Valve Body Assembly and Valve Detail.

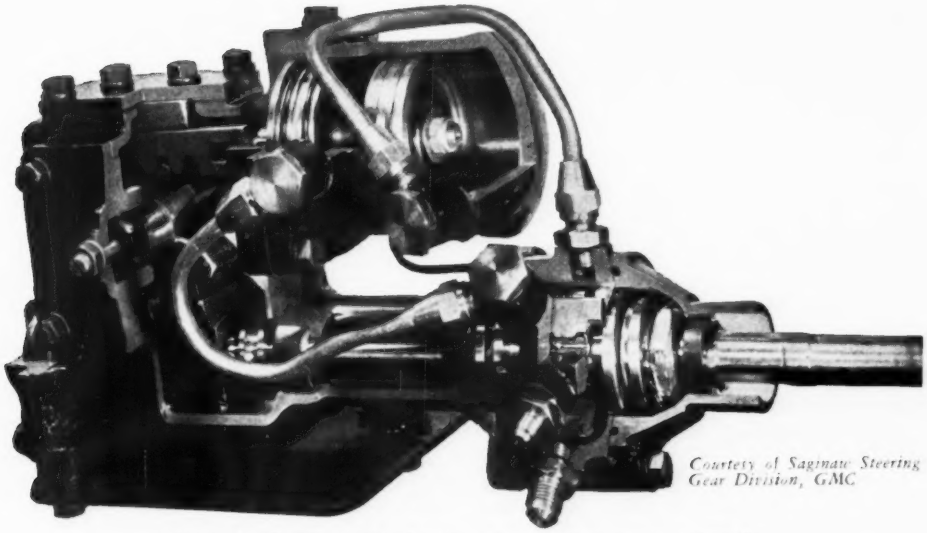


Figure 5 — General Motors-Saginaw Power Unit (partially sectioned).

Should the driver release his wheel entirely, the caster effect (supplied by the fore-and-aft inclination of the king pins) will tend to turn the front wheels to their straight-ahead position, thus changing the "pull" in the drag link to a "push." Since the mechanical steering gear is by no means irreversible, this push tends to rotate the worm towards its straight ahead position. The free steering wheel offers no resistance, thus the valve operating block remains in its neutral position, and the road wheels return to a straight-ahead position in the same manner and as quickly as in a conventional mechanical steering system.

Now suppose that a road rut, soft road shoulder or blown right front tire is encountered at high speed. With a conventional steering gear and an inattentive or physically weak driver, any of these hazards would cause the car to plunge towards the right ditch and an accident despite the driver's frantic efforts to turn the front wheels to the left. With a power steering gear however, only a tiny effort is needed to overrule the adverse minor mechanical reaction and to instantly substitute a powerful and favorable hydraulic effort which keeps the car on the road.

Chrysler has already taken advantage of the availability of power by reducing the overall ratio of the mechanical elements in its power steering system, which also reduces the amount of steering wheel movement required for any maneuver and makes steering faster and more responsive to the driver's wishes. For example in one car, the conventional steering system has an overall ratio of 26.2 and requires 5½ turns of the steering wheel to change the front road wheels from full right to full left: corresponding figures for the power steering gear in this car are only 16.2 and 3½ turns.

And lastly, should the very remote possibility of hydraulic failure occur, the standard highly-efficient all mechanical steering gear is instantly and completely available without thought or other action by the driver.

THE GENERAL MOTORS SAGINAW POWER STEERING SYSTEM

(Cadillac, Buick, Oldsmobile, Pontiac, Chevrolet, Lincoln)

As illustrated in the partially sectionalized Figure 5, the Saginaw gear is also of the integral type in which the basic mechanical steering gear, the hydraulic booster and its Davis spool-type control valve are all combined in one compact housing. It is supplied with oil at a pressure up to 750 psi by either an Eaton six-lobed pump or a Vickers vane-type pump driven by a Vee belt from the engine's crankshaft and drawing from a small oil reservoir.

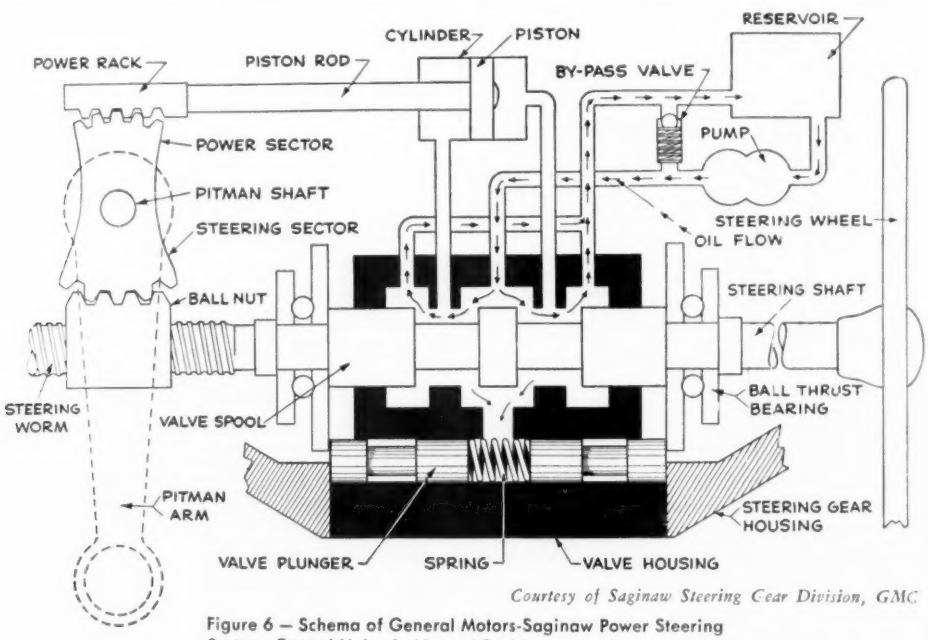
The mechanical element of this steering gear is the now well-known low-friction Saginaw recirculating-ball type in which a number of steel ball bearings act as a highly efficient rolling thread between the steering worm and its ball nut, the latter being geared to a sector on the pitman shaft. Hydraulic assistance is furnished by a single double-acting piston having a toothed or racked piston rod also meshing with a gear sector on the pitman shaft. Almost the entire control system is embodied in the unbelievably simple Davis open-center spool-type control valve which is concentric with the steering shaft and hydraulically connected to the power cylinder by only two short rigid tubings.

Figure 6 schematically illustrates the entire system and purposely magnifies the Davis valve so that the simplicity with which it performs its several important functions can be more easily appreciated.

The valve spool with its two high-capacity annular grooves is accurately fitted into a correspondingly grooved valve housing in which it can move both axially and radially. Axial or endwise movement of the spool (and the steering shaft with which it is essentially integral) is restricted to a maximum of about 0.060 inches (valve movement and full overlap) by a pair of ball thrust bearings. The valve housing is also bored axially around the spool cavity to contain as many as five valve-plunger and spring sets like the single one shown in the figure. Since the valve plungers are a recent improvement not fundamental to the operation of the Davis valve, let us first examine the latter.

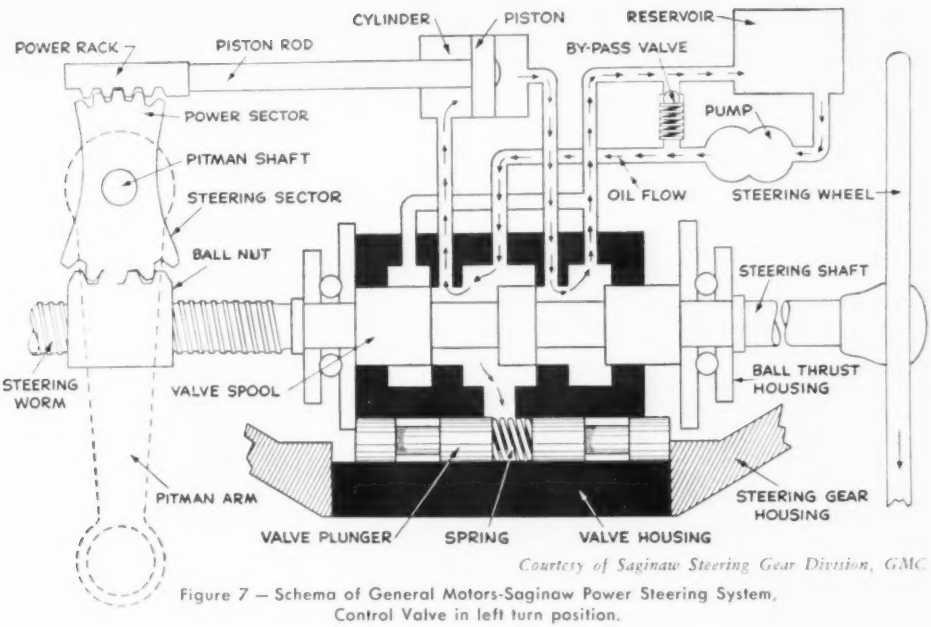
From Figure 6, which illustrates the Davis valve in its central inactive or "neutral" position, it will be noted that oil from the pump enters the "open center" of the valve housing, flows easily and freely around both sides of the central land on the spool and returns immediately to the reservoir without even approaching the power cylinder. Since all passages are quite open and frictionless in the valve's neutral position, and since the valve remains in this position at all times except when steering is actually occurring, the valve's "open center" feature reduces pumping losses to an irreduceable minimum.

Figure 7 illustrates the operation of the valve when the driver initiates a sharp left turn. Since front-wheel and steering-linkage resistance tends to keep the pitman arm and ball nut stationary, the resultant resistance causes the steering worm, shaft and valve spool to screw upwards very slightly and imperceptibly towards the driver. The central land of the valve spool accordingly shuts off oil pressure to the head of the power piston and simultaneously enlarges the passage to the reservoir; at the same time the central land has widely opened the port connecting to the underside of the power piston so that it is now subjected to full pump pressure. The power piston is forced to the right, rotates the pitman shaft in the clockwise direction required for a left turn, and simultaneously moves the ball nut steering worm and valve spool back to its central neutral position. In brief, power assistance is developed only as long as the driver demands it by rotating the wheel and shuts itself off promptly when he merely "holds" the wheel, such as when driving straight ahead or along a regular curve. It should be understood that full pump pressure is applied to one side of the power piston only when the spool is fully displaced to either limit, which normally occurs only during parking or emergency action; during normal driving the spool is displaced only slightly and affords smoothly graduated power assistance by applying differential oil pressures to both sides of the power piston. When the driver releases his wheel entirely, the car's front wheels will automatically return to their straight-ahead position due to steering geometry. Road shocks are similarly and immediately opposed and neutralized by hydraulic action. As a further refinement, the



Courtesy of Saginaw Steering Gear Division, GMC

Figure 6 — Schema of General Motors-Saginaw Power Steering System, Control Valve in Neutral Position.



Courtesy of Saginaw Steering Gear Division, GMC

Figure 7 — Schema of General Motors-Saginaw Power Steering System, Control Valve in left turn position.

ball check by-pass valve shown schematically in Figure 6 (but actually built into the valve body itself) is provided to insure easy all-mechanical steering in the remote event of a pump failure.

The previously mentioned valve plunger and spring sets are used solely to develop a sense of road reaction or "feel" in the power system: without these plungers the spool valve is fully operable as a "100% assistance" gear wherein the slightest finger-tip touch to the steering wheel will excite power assistance. Since some drivers feel that such complete power assistance leads to over-steering, hyper-sensitivity under straight ahead driving and loss of road "feel," the valve plungers have been added to satisfy these drivers by providing a definite "feel of the road" and by insuring that during normal straight-ahead level-road driving no power assistance is provided. As can be seen from either Figure 6 or 7, each plunger set consists of two identical pistons which are always forced apart by a combination of spring pressure and oil pressure on their innermost surfaces. Their spring pressure alone tends to maintain the valve spool in its neutral position; however, spring pressure is reinforced by hydraulic pressure which increases up to full pump pressure when the spool is fully displaced. The effect of the plungers is to apply a small threshold preload to the system which must be manually overcome by the driver before power assistance is generated. Obviously the manufacturer can vary this threshold or "feel" from nothing up to manual steering effort as the public may desire; the plungers in general use require the driver to exert about a three-pound pull at the rim of his steering wheel to obtain "initial" power.

All-climate lubrication for the hydraulic system is provided by about two quarts of an approved Automatic Transmission Fluid Type A. The fluid level in the reservoir of the pump should be checked every 1000 miles of vehicle operation. The "chuck" or mechanical portion of the gear is preferably lubricated with a special grease.

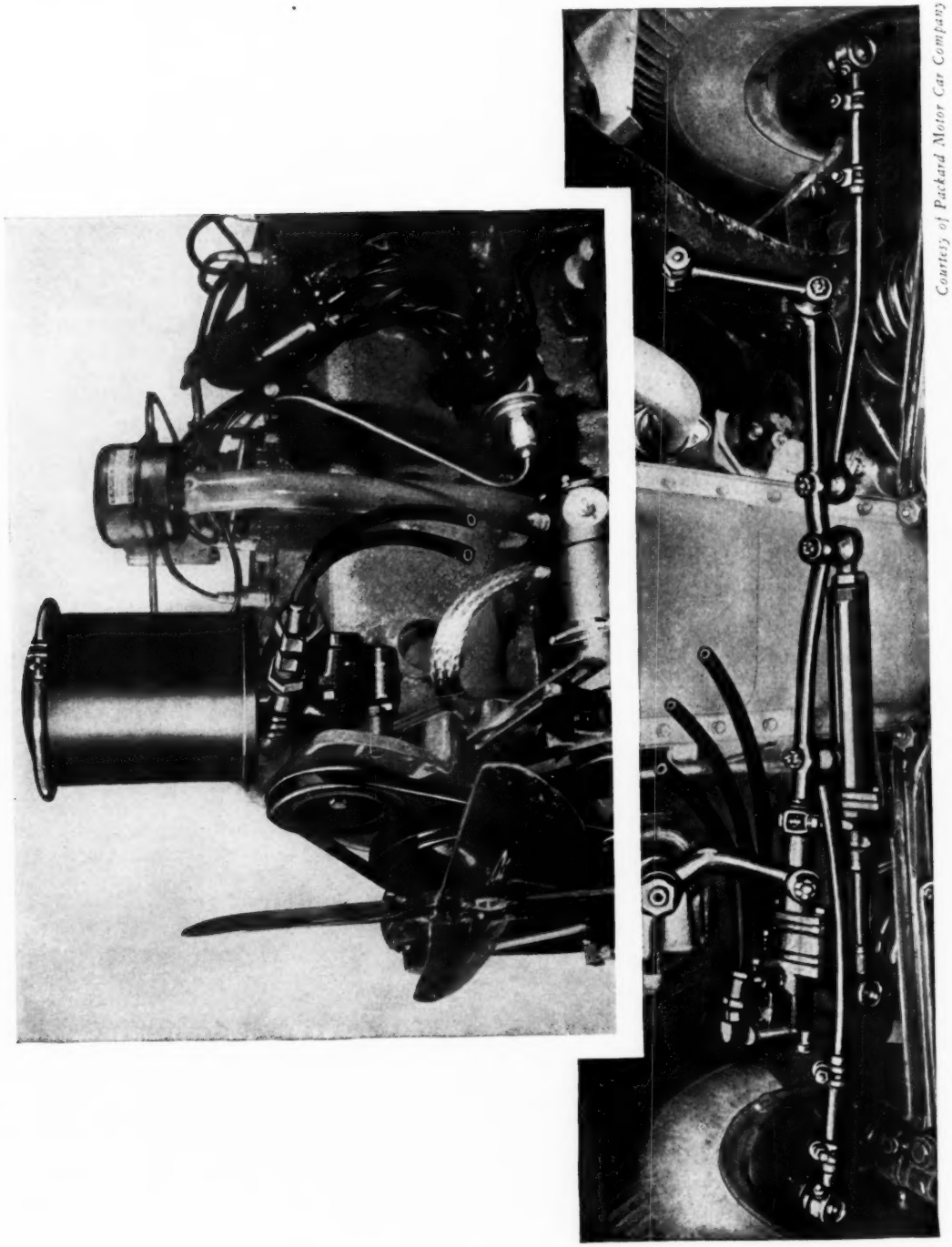
The PACKARD (BENDIX) POWER STEERING SYSTEM

As may be seen in Figure 8, this system comprises the conventional belt-driven hydraulic pump with oil reservoir, a Bendix-designed control valve located in the enlarged end of the cross link for actuation by the pitman arm, and a power cylinder of the double-acting piston type connected between the steering linkage and the car's frame.

The fluid reservoir contains a filter element protected by a spring-loaded relief valve. Since the system is closed, a vent-valve is also provided which opens when interior air pressure exceeds from 1½ to 8 psi.

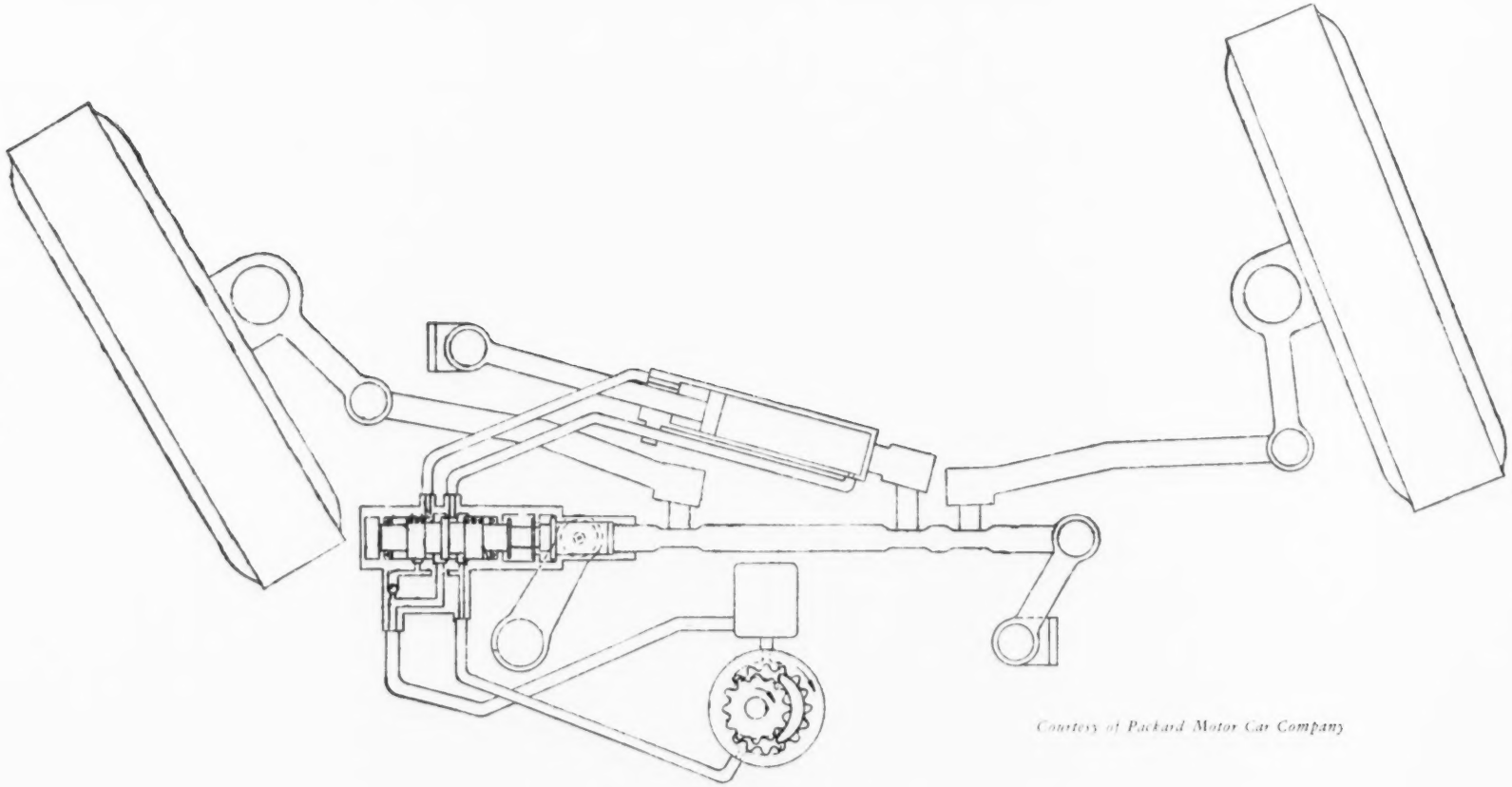
The belt-driven pump produces fluid pressure up to 650 psi, and is equipped with a flow-control valve set for a volume of 1.9 gpm at normal car speeds and 1.4 gpm with engine idling. A separate piston-type relief valve opens at 650 psi. Should oil pressure fail, another valve permits bypassing of oil around the pump so that normal all-mechanical steering is provided.

As indicated schematically in Figure 9, the con-



Courtesy of Packard Motor Car Company

Figure 8 — Installation of Packard-(Bendix) Linkage Type Power Steering System.



Courtesy of Packard Motor Car Company

Figure 9 — Schema of Packard-(Bendix) Linkage Type Power Steering System.

trol valve spool is connected to the pitman arm through a ball joint whereas the control valve body is an integral part of the steering linkage cross link. The spool is formed with two annular channels connected respectively through individual passages with corresponding reaction chambers at each end of the spool. In the straight-ahead driving position, the spool and sleeve are therefore maintained in their neutral "free flow" position through hydraulic pressures in the reaction chambers.

Figure 9 also indicates the action of the system when the driver initiates a left turn. Upon rotating the steering wheel counter-clockwise, the pitman arm moves clockwise, urging the valve spool to the right within the valve body. Oil pressure is accordingly admitted to the right chamber of the power cylinder (and simultaneously vented to a greater degree than normal from its left chamber), moving the power cylinder and steering linkage to the right. At the same time, oil at pump pressure passes through the orifice in the right land of the valve spool into the right reaction chamber, thereby tending to move the spool back to its central position. Power assistance is therefore cancelled if the driver relaxes manual effort at the steering wheel. This steering device transmits road reaction or "feel" to the driver.

The hydraulic system contains approximately 2 quarts of Ultramatic Drive Fluid or Automatic Transmission Fluid Type A.

The Possible Future

The modern automobile with automatic transmission, power steering and the now-common conveniences may contain as many as seven different independent pumps. In due time it is presumed that the designers may substitute a single constant-volume pump with suitable modulators drawing a single fluid through a single effective filter. As has already been partially accomplished in one motor bus, perhaps the engine, automatic transmision, power-steering, power brakes, windshield wiper, convertible top and even the differential could be persuaded to operate on one fluid.

Power steering is currently in the accessory class; i.e., it is merely applied or adapted with minimum possible change in the existing car design. As the popularity of power steering continues to increase, however, the design of the car can and should be modified to integrate the power steering gear into a logical whole. For example (as Chrysler has already demonstrated) power steering will permit a considerable reduction in steering gear ratio, resulting in faster, more responsive, and safer steering.

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